Schiff Hardin

Schiff Hardin LLP
233 South Wacker Drive
Suite 6600
Chicago, IL 60606

T 312.258.5500
F 312.258.5600

schiffhardin.com

April 27, 2016

Renee Cipriano
312.258.5720
rcipriano@schiffhardin.com

VIA FIRST CLASS MAIL
AND EMAIL (weber.rebecca@epa.gov)

Ms. Rebecca Weber
USEPA – Region 7
11201 Renner Boulevard
Mail Code: AWMD
Lenexa, Kansas 66219

Re: Site Specific Demonstration Under Section 3.2 of 40 CFR Part 51, Appendix W: AERMOD 15181: Low Wind Beta Options (LOWWIND# and ADJ U*)

Dear Ms. Weber:

On behalf of Ameren Missouri (Ameren), we write in follow-up to both Ameren's and the Missouri Department of Natural Resources' (MDNR) prior request to EPA to authorize the use of AERMOD version 15181 low wind beta options (LOWWIND3 and ADJ U*) at Ameren's Labadie Energy Center to model attainment of the 2010 1-hour SO2 NAAQS. In accordance with Section 3.2 of 40 CFR Part 51, Appendix W, Ameren has provided all the necessary information to substantiate EPA's site-specific approval of the beta options. We respectfully request an update on the status of EPA Region 7's consideration of the site-specific request, and the status of EPA's Model Clearinghouse's concurrence. Specifically, please confirm that Region VII has submitted this request and all relevant data to the Model Clearinghouse for review and timely consideration.

As you may recall, on December 9, 2015, MDNR submitted a request to EPA to consider the use of LOWWIND3 and ADJ U* at Labadie. On February 16, 2016, EPA issued its proposed nonattainment designation for Labadie for the 2010 SO2 NAAQS. In its proposal, EPA refused to consider AERMOD's low wind beta options even though their use demonstrated attainment of the 2010 SO2 NAAQS for Labadie. In response, on February 24, 2016, Ameren requested an in-person meeting with EPA Region 7 to discuss a Labadie-specific approval for the use of beta options in accordance with Section 3.2.2(b) of Appendix W. In turn, on March 7, 2016, EPA Region 7 requested additional information from MDNR in order to consider approving the use of low wind beta options for Labadie. On March 24, 2016, following a conference call with EPA Region 7, Ameren provided responsive information to each of EPA's information and document requests.

Over four weeks have passed and both Ameren Missouri and MDNR continue to await a site-specific determination from EPA. In the interim, Ameren Missouri continues to collect monitoring data from the ambient air quality monitors sited around Labadie. Consistent with Ameren's prior data submissions, the additional monitoring data continues to confirm that AERMOD modeling using the low wind beta options correlates more closely to actual air quality monitoring results than AERMOD using non-site specific and generic default assumption. Ameren will provide EPA updated monitoring data (quality assured through 1Q 2016) via electronic submission early next week, Ameren encloses with this correspondence two additional publications from AECOM supporting the use of low wind beta options. The first is a scientifically peer-reviewed paper published in the Air & Waste Management Association journal (submitted on October 27, 2015). The second is a white paper submitted on March 31, 2016, to the docket of the U.S. Court of Appeals for the Ninth Circuit in *Sierra Club v. McCarthy*, No. 15-15894. Both publications provide additional support for use of AERMOD's low wind beta options, and respond to certain Sierra Club critiques of those options.

In sum, Ameren contends that use of AERMOD's low wind beta options has been demonstrated to have statistically improved performance over that of the regulatory default version of AERMOD for Labadie. Sufficient scientific peer-review has occurred, and a year of actual monitoring data substantiate use of low wind options at Labadie. Accordingly, consistent with EPA regulations and guidance, the air quality modeling results obtained from the use of low wind beta options are a reliable indicator of attainment status in the area around Labadie.

Please contact Steve Whitworth, Senior Director Environmental Policy and Analysis (314 554 4908) as soon as possible to update Ameren on the status of its site-specific request. We look forward to your response.

Sincerely,

Renee Cipriano

RC/dl
Enclosures

cc: Susan B. Knowles – Ameren Services Co.

ATTACHMENT 1

AERMOD Low Wind Speed Improvements: Status Report and New Evaluations

Paper # 935

Robert J. Paine, Christopher J. Warren, and Olga Samani
AECOM, 250 Apollo Drive, Chelmsford, MA 01824

ABSTRACT

Some of the most restrictive dispersion conditions and the highest model predictions for AERMOD occur under low wind speed conditions, but before 2010, there had been limited model evaluation for these conditions. After a 2010 AECOM study, EPA proceeded to implement various improvements to the AERMET meteorological pre-processor (to address underpredictions of the friction velocity in low wind conditions) as well as the AERMOD dispersion model (to address under-predictions of the lateral wind meander). There have been several AERMOD releases with various options to address this issue, as well as additional model evaluations to further test the AERMOD implementation.

In July 2015, EPA proposed an updated set of options for AERMET and AERMOD for implementation as default options in the model. As part of the public comments, the Sierra Club provided new evaluations that led to questions as to whether the low wind options are sufficiently protective of air quality standards, especially the short-term SO_2 and NO_2 NAAQS. This study provides updated evaluation results to address these new concerns.

INTRODUCTION

When the United States Environmental Protection Agency (EPA) issued a proposed rulemaking to revise Appendix W to 40 CFR part 51, published in the July 29, 2015 Federal Register (80 FR 45340), it also released a revised version of AERMOD (15181), which replaced the previous version of AERMOD dated 14134. In the proposed revision to Appendix W, EPA proposed refinements to the default options in its preferred short-range model, AERMOD, involving low wind conditions. These refinements, included as beta options in version 15181 of AERMOD, involve an adjustment to the computation of the friction velocity ("ADJ_U*") in the AERMET meteorological pre-processor and a higher minimum lateral wind speed standard deviation, sigma-v (σ_v), as incorporated into the "LOWWIND3" option. The proposal indicates that "the LOWWIND3 BETA option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, uses the FASTALL approach to replicate the centerline concentration accounting for horizontal meander, but utilizes an effective sigma-y and eliminates upwind dispersion"[1]. At the public hearing for the proposed Appendix W revisions (the 11th Modeling Conference), EPA provided[2] evaluation results to support their proposal.

In comments to the docket on behalf of industrial trade organizations (the American Petroleum Institute and the American Iron & Steel Institute) to support EPA's low wind proposal, AECOM included references to a recently published peer-reviewed journal article[3] and supplementary evaluation information[4] involving tall-stack field databases to support the EPA proposal for incorporation of the low wind options noted above as default options.

Although most comments to the EPA docket supported the proposed low wind options, the Sierra Club issued comments[5] to the contrary, recommending that EPA should not adopt the proposed low wind options as defaults in the AERMOD modeling system. The Sierra Club analysis is further discussed below.

The purpose of this study has been to review the Sierra Club comments and modeling analysis and to rerun the evaluation for some of the databases for tall point sources used by the Sierra Club. The statistical metrics used in our evaluation are focused upon the design concentration for the 1-hour SO_2 National Ambient Air Quality Standard (NAAQS), which has a statistical form that is not represented in the statistical metrics used in the Sierra Club's model evaluation. The focus on the statistical 1-hour SO_2 design concentration (99^{th} percentile daily maximum concentration over a year) is most appropriate for tall point sources such as power plants as that is commonly the criteria pollutant of interest. For low-level sources, other criteria pollutants such as carbon monoxide, which does not have statistically-based NAAQS design concentrations, can also be important.

SUMMARY OF AERMOD LOW WIND OPTIONS

In 2005, the EPA promulgated a new dispersion model, AERMOD[6], which replaced the Industrial Source Complex (ISC) model[7] as the preferred model for short-range air dispersion applications. Historically with ISC, winds below 3 knots (or 1.5 m/s) were presumed to be calm and were not modeled. As AERMOD and available wind measurements at airports have evolved since 2005, it has become quite routine for modeling applications (including those conducted for New Source Review) to include hours with wind speed observations much lower than 1.5 m/s. The instrumentation and recording methods for Automated Surface Observing System (ASOS) stations have also evolved. Some ASOS stations are now equipped with sonic anemometers with the ability to record winds less than 0.1 m/s. The inclusion of lower wind speed observations into AERMOD meteorological databases was made possible with these ASOS stations. Modeling issues under conditions of low wind speeds have become more prevalent with EPA's recommended procedures and the AERMINUTE tool for incorporating sub-hourly winds into AERMOD's meteorological databases.

One suspected area of AERMOD model bias has been for the situation of very low wind speeds (e.g., less than 1 m/s), stable conditions, and near-ground releases, as documented by Paine et al., 2010 (the "AECOM study", co-funded by the American Petroleum Institute and the Utility Air Regulatory Group[8]). With lower wind speeds more frequently being modeled, the use of these values as input to AERMOD is pushing the known bounds of a steady-state Gaussian model, which inherently assumes uni-directional wind flow. Because this is sometimes not the case during near-calm conditions, AERMOD or any other steady-state Gaussian model must be applied with caution, because the concentration approaches infinity at zero wind speed. The results of using very low wind speed input to AERMOD are the simulation of a plume that is generally too compact due to the lack of along-wind dispersion in the model formulation and under-representation of wind direction variability. As a result of the low wind issue, the AECOM study was conducted and the results were provided to EPA that specifically examined and improved AERMOD's ability to predict under low wind speed stable conditions.

The AECOM 2010 study examined two aspects of the model: (1) the meteorological inputs, as it related to u_* (friction velocity) and (2) the dispersion model itself, particularly the minimum lateral turbulence (as parameterized using sigma-v) assumed by AERMOD. As part of phase 1 of the study (involving three research-grade meteorological databases), the authors (Paine et al., 2010) concluded that their evaluation indicated that in low wind conditions, the u_* formulation in AERMOD underpredicts this important planetary boundary layer parameter. This results in an underestimation of the mechanical mixing height, as well as underestimates of the effective dilution wind speed and turbulence in stable conditions.

As part of phase 2 of the AECOM 2010 study (involving two low-level tracer release studies: Oak Ridge and Idaho Falls), the authors concluded that the AERMOD minimum sigma-v value of 0.2 m/s was too low by about a factor of 2, especially for stable, nighttime conditions.

The AECOM 2010 study found that the default AERMOD modeled concentrations were being over-predicted by nearly a factor of 10 for the Oak Ridge database and a factor of 4 for the Idaho Falls database. However, the proposed adjustments to the u_* formulation in AERMET and the incorporation of a minimum sigma-v in AERMOD substantially improved the model performance. The results of the AECOM 2010 study were provided to EPA in the spring of 2010.

EPA responded appropriately to these issues by incorporating low wind model formulation changes as beta options in AERMET and AERMOD versions 12345, 13350, 14134, and 15181. The formulation changes to AERMET were similar to those suggested by AECOM in their 2010 report, although EPA relied upon a Qian and Venkatram (2011) peer-previewed paper[9] for the AERMET formulation of the friction velocity ("ADJ_U*") adjustments. As a result of experience and comments received since the initial low wind implementation in late 2012, EPA proposed its recommended options in July 2015 for incorporation as defaults in the AERMOD modeling system.

SIERRA CLUB EVALUATION OF LOW WIND OPTIONS IN AERMOD VERSION 15181

The Sierra Club initially expressed its concerns about the AERMOD low wind options in a Camille Sears presentation[10] made at the 2013 EPA Modeling Workshop. As part of their comments on the proposed EPA changes to AERMOD presented in 2015, Camille Sears conducted additional evaluations on some of the evaluation databases that EPA has posted[6] for AERMOD studies. The specific evaluation databases selected by the Sierra Club included Baldwin, Kincaid, Lovett, Tracy, and Prairie Grass, with features noted below.

- Baldwin (1-hr SO_2): Rural, flat terrain, 3 stacks, stack height = 184.4 m, 1 full year
- Kincaid (1-hr SO_2): Rural, flat terrain, 1 stack, stack height = 187 m, about 7 months
- Lovett (1-hr SO_2): Rural, complex terrain, stack height = 145 m, 1 full year
- Tracy (1-hr SF_6): Rural, complex terrain, 1 stack, stack height = 90.95 m, several tracer release hours
- Prairie Grass (1-hr SF_6): Rural, flat terrain, 1 stack, release height = 0.46 m (no plume rise), several tracer release hours.

The evaluation techniques selected by Camille Sears for AERMOD were designed by EPA in the early 1990s, and the evaluation results were updated for various versions of AERMOD up to 2003 and 2005, when the most recent evaluation documents[11,12] were published. EPA's model evaluation procedures were developed to evaluate the ability of the model to estimate peak 1-hour average concentrations. This was appropriate for all criteria pollutants at that time which had deterministic short-term NAAQS, for which only a single excursion per year was allowed. This preceded the promulgation of statistically-based probabilistic forms of the 1-hour NAAQS for SO_2 and NO_2 (99^{th} and 98^{th} percentile of the daily 1-hour maximum values per year). For example, for SO_2, the ranked 1-hour concentration for the "design concentration" at any location (which has the same statistical form of the NAAQS) could theoretically range anywhere between the 4th highest and the 73rd highest 1-hour concentration in a full year.

EPA's recommended model evaluation statistic (developed prior to the promulgation of revisions to the SO_2 and NO_2 NAAQS in 2010) is the "robust highest concentration" (RHC), which focuses upon a fit involving the highest 26 concentrations among data from all monitor locations. EPA's 1992 model evaluation guidance[13] references the RHC statistic as the preferred approach. While this statistic was useful for the previous forms of the short-term NAAQS, including the SO_2 secondary NAAQS (2^{nd}-highest 3-hour concentration, which is the 99.93^{th} percentile value), it is clear that this statistic is inconsistent with the current short-term NAAQS for SO_2 and NO_2. As such, in evaluating model performance, especially for tall point sources for which the determination of modeled SO_2 NAAQS compliance is highly important, it is appropriate to focus upon the form of the 1-hour design concentrations.

The results of the Sierra Club evaluation are provided in Figure 1 as a screen capture from their comment document. The relevant lines of results to review in the figure are the third line (AERMOD default – no low wind options) and the fifth line (AERMOD with both ADJ_U* and LOWWIND3 options). Although we view the statistic presented as inconsistent with the 1-hour NAAQS and therefore can potentially misrepresent model performance in that regard, the following items are worth noting:

- Even with the RHC approach that was used, the Baldwin and Prairie Grass results show over-predictions or unbiased results with the low wind option; they are not reviewed here.

- The Kincaid and Lovett results show apparent under-predictions even for the default model, with slightly more under-prediction for the low wind options. However, the 100th percentile statistic addressed by the RHC misrepresents the more relevant and more stable 99th percentile (for SO_2) and 98th percentile (for NO_2) daily maximum NAAQS statistics. We also note below that the Kincaid evaluation study omitted important SO_2 sources that make this evaluation data unreliable.

- The short-term tracer studies (Tracy and Prairie Grass) are not amenable to an operational evaluation study that uses a long period (such as a full year) of data to address a wide range of meteorological conditions. Therefore, we did not use those databases in this supplemental study except for a brief look at the Tracy evaluation.

Figure 1 Summary of Sierra Club RHC Statistical Results

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A summary of Modeled RHC/Monitored RHC values for these modeled scenarios and field studies is presented in the following table:

Scenario	Baldwin (1-hr SO_2)	Kincaid (1-hr SO_2)	Lovett (1-hr SO_2)	Tracy (1-hr SF_6)	Prairie Grass (1-hr SF_6)
v. 02222	1.42	0.84	0.90	1.05	1.19
v. 12345	1.56	0.83	0.78	1.12	1.16
v. 15181	1.55	0.83	0.77	1.12	1.17
v. 15181, ADJ_U*	1.55	0.83	0.91	0.53	1.19
v. 15181, ADJ_U*, LOWWIND3 (0.3, 0.5, 0.95)	1.40	0.72	0.79	0.42	0.95

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The results of the evaluation with low wind options could depend upon whether the measured turbulence data (especially the horizontal turbulence data) is withheld from the modeling. The horizontal turbulence issue is noteworthy because recent EPA guidance indicates that the hourly averages of wind direction fluctuations should use four 15-minute averages, thus neglecting wind direction meander among the 15-minute periods. In addition, EPA may consider[14] that the use of the observed sigma-theta (and possibly sigma-w data), in addition to the low wind meander adjustments, could "over-correct" for the low wind issue.

In some research-grade experiments, such as Tracy, the turbulence data is obtained from sonic anemometers, which could result in higher turbulence measurements in low winds because these instruments have a very low wind detection threshold as opposed to more commonly-used cup and vane wind systems. Sonic anemometers can have operational difficulties for routine monitoring in general due to problems in humid climates with wet probe errors and a very large power requirement[15], which makes battery backup in the event of power outages problematic. In addition, the hourly averages of the horizontal wind direction standard deviation (sigma-theta) for Tracy[16] and the other databases developed for EPA during the Complex Terrain Model Development program used true hourly averages rather than averaging four 15-minute averages. This can result in a double-counting of meander in AERMOD and can possibly overstate the vertical turbulence component as well. Therefore, the option to remove the observed turbulence input to AERMOD for the low wind runs may be dependent upon the averaging used. The instruments used in all of the databases that we ultimately selected for evaluation used hourly averages consisting of four 15-minute averages, thus not double-counting the wind meander.

DESIGN OF OUR STATISTICAL EVALUATION

To address the issues brought up by the Sierra Club in its model evaluation, we provide the results of a similar evaluation analysis with the following features:

- Alternative statistical measures (more relevant for the form of the 1-hour SO_2 NAAQS) are reported, as further discussed in bullets below.

- Three tall-stack databases were considered, two of which were modeled by the Sierra Club, plus one additional AERMOD evaluation database (Clifty Creek) to increase confidence in the overall results: Lovett, Kincaid, and Clifty Creek. Lovett represents a complex terrain setting, Kincaid a flat setting, and Clifty Creek represents an intermediate setting with the power plant in the Ohio River gorge, but with stack top still higher than the higher elevation monitors.

- For the RHC statistic, we also used the daily 1-hour maximum instead of all hourly values, to be more consistent with the form of the 1-hour NAAQS.

- For the RHC statistic, we also discarded (for the case of SO_2 for a year of data) the top 3 daily 1-hour maximum values so that the statistic estimates the correct form of the standard (this statistic can be referred to as "R4HC" because it estimates the 4^{th} highest concentration).

- We also conducted an R4HC evaluation for each monitor separately, and then took the geometric mean of the modeled-to-observed ratios over all monitors to determine the overall model performance with the monitors each given equal weight.

- In supplemental information provided separately to EPA (too lengthy to include in this paper), we provided an appendix for each database evaluated, we include quantile-quantile (Q-Q) plots for each monitor to pair the evaluation in space.

- In this paper, we show plots of the observed and predicted 99^{th} percentile peak daily 1-hour maximum concentrations in ranked pairs to focus on the form of the SO_2 NAAQS and ability of the model to prove a predicted design concentration that is at least as high as the highest observed design concentration.

- Our modeling options included all default options, use of the ADJ_U* option in AERMET (but default AERMOD – no LOWWIND3), and ADU_U* plus LOWWIND3. Due to the underlying science that justifies the correction to the friction velocity formulation (ADJ_U*), we did not consider LOWWIND3 without ADJ_U*.

LOVETT EVALUATION RESULTS

Description of Field Study Setting

The Lovett Power Plant study (Paumier et al.[17]) consisted of a buoyant, continuous release of SO_2 from a 145-m tall stack located in a complex terrain, rural area in New York State. The data spanned one year from December 1987 through December 1988. Data available for the model evaluation included 9 monitoring sites on elevated terrain; the monitors were located about 2 to 3 km from the plant. The monitors provided hourly-averaged concentrations. A map of the terrain overlaid with the monitoring sites is shown in Figure 2. The important terrain feature rises approximately 250 m to 330 m above stack base at about 2 to 3 km downwind from the stack. The plant was a base-loaded coal-fired power plant with no flue gas desulphurization controls; hourly emissions and stack flow rate and temperature data were available. Meteorological data included winds, turbulence, and ΔT from a tower instrumented at 10 m, 50 m, and 100 m. National Weather Service surface data (used for cloud cover) were available from a station 45 km away.

AERMET/AERMOD version 15181 was run for the Lovett evaluation database using the following 8 configuration options:

- AERMET Default / AERMOD Default, including all observed turbulence;
- AERMET Default/ AERMOD Default with all observed turbulence removed;
- AERMET ADJ_U* / AERMOD LOWWIND3, including all observed turbulence;
- AERMET ADJ_U* / AERMOD LOWWIND3 with all observed turbulence removed; and
- AERMET ADJ_U* / AERMOD LOWWIND3 with observed horizontal turbulence removed, but retaining the vertical turbulence data.
- AERMET ADJ_U* / AERMOD (default), including all observed turbulence;
- AERMET ADJ_U* / AERMOD (default) with all observed turbulence removed; and
- AERMET ADJ_U* / AERMOD (default) with observed horizontal turbulence removed, but retaining the vertical turbulence data.

The EPA-proposed model option parameters (0.3, 0.5, 0.95) were selected for the LOWWIND3 model runs, consistent with the Sierra Club report.

Results of the 99th Percentile Concentration Comparison

To be more consistent with the form of the 1-hour NAAQS, the 4th highest (99th percentile) daily peak 1-hour SO_2 concentrations observed at each monitor location were compared against the model-predicted concentrations of similar rank. Summarized in Figure 3 are the predicted concentrations determined using model default and low wind options as stated above. The overall results indicate that the modeling scenario using low wind options, but without turbulence, had an overall maximum 4th highest daily 1-hour concentration across all monitors greater than the overall highest observed.

Discussion of Lovett Evaluation Results

After we closely replicated the Sierra Club results, we investigated alternative evaluation approaches for the predicted and observed concentrations. We computed RHC statistics for the 1) highest 1-hour concentration, 2) the 4th highest 1-hour concentration (discarding the top 3 values, but using all hourly values, and 3) the 4th highest daily maximum 1-hour averaging periods of SO_2 concentrations for each monitoring site. For the third set of statistics, we calculated a geometric mean of these ratios to gain a better understanding of the overall model performance that accounts for all monitors; see Table 1).

Figure 2 Map of Lovett Power Plant and Monitor Locations

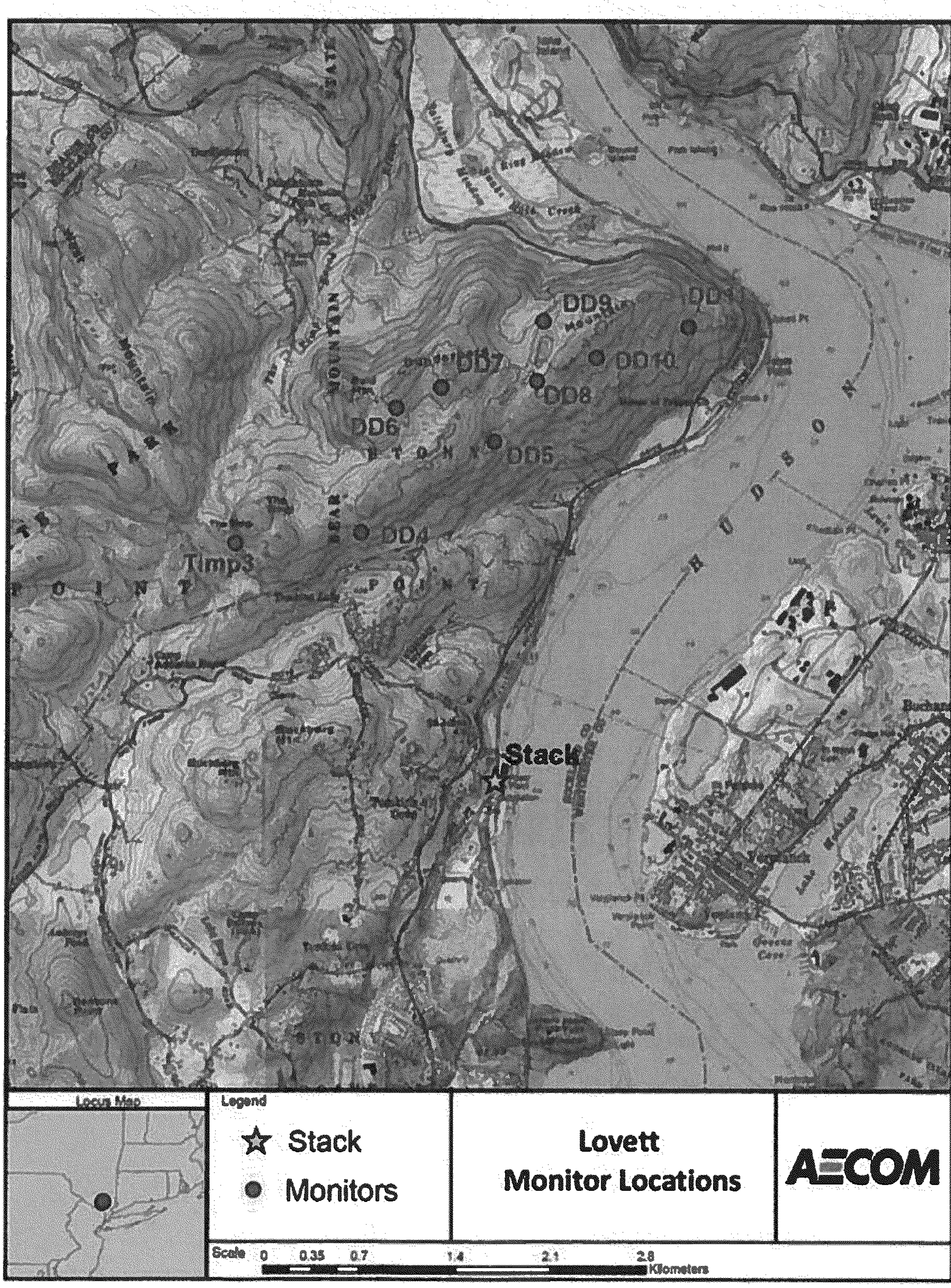


Figure 3 Histogram of the 4th Highest Daily Peak 1-hour SO_2 Concentrations

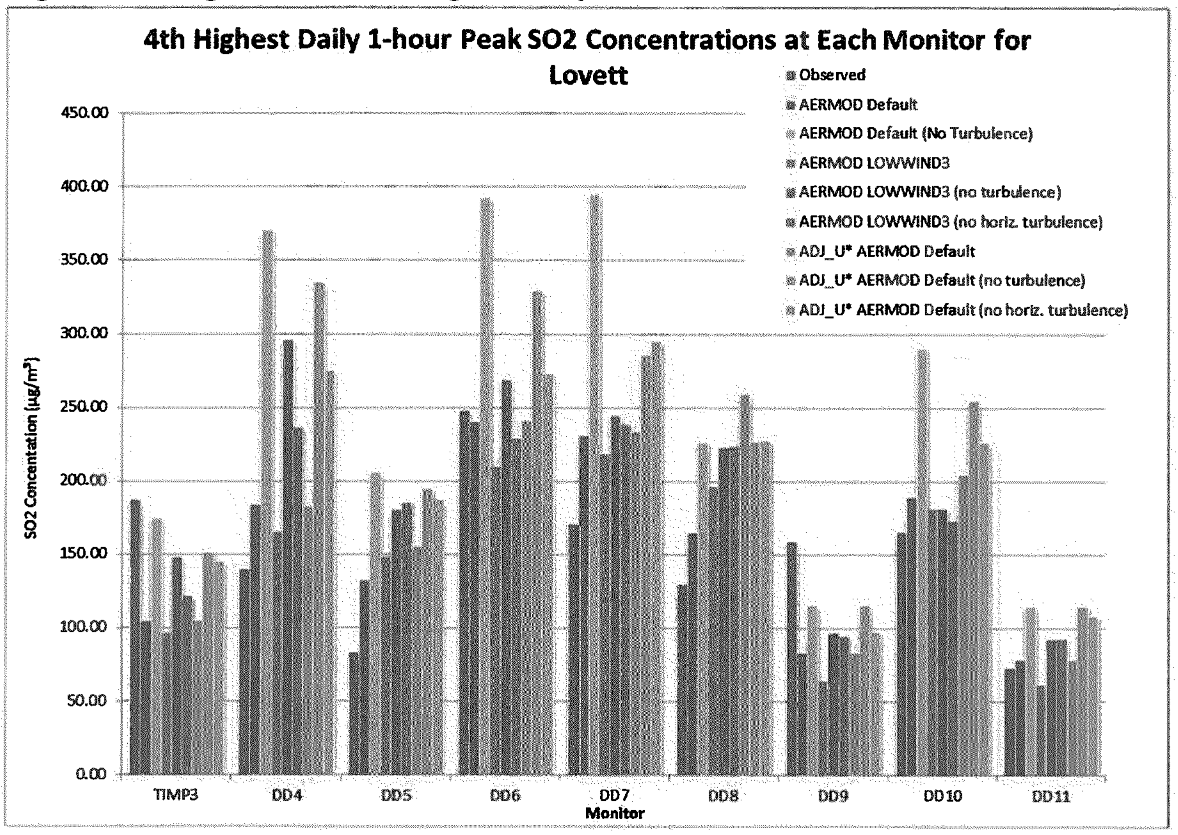


Table 1 Ratio of Predicted-to-Observed Robust 4th Highest Daily Peak Concentration (R4HC; 99th Percentile) for Each Monitor at Lovett

Monitor	AERMOD 15181, Default, all turb.	AERMOD 15181, Default, no turb.	AERMOD 15181, all low wind options, all turb.	AERMOD 15181, all low wind options, no turb.	AERMOD 15181, all low wind options, no horiz. turb.	AERMOD 15181, ADJ_U*, all turb.	AERMOD 15181, ADJ_U*, no turb.	AERMOD 15181, ADJ_U*, no horiz. turb.
TIMP3	0.53	0.62	0.40	0.58	0.52	0.47	0.51	0.53
DD4	1.49	3.19	1.26	2.49	1.83	1.40	3.08	2.16
DD5	1.55	2.85	2.13	2.18	2.06	2.26	2.74	2.40
DD6	0.81	1.46	0.63	1.00	0.79	0.69	1.25	0.92
DD7	1.29	1.86	1.29	1.42	1.18	1.33	1.65	1.61
DD8	1.03	1.47	1.63	1.19	1.27	1.84	1.23	1.28
DD9	0.38	0.60	0.32	0.52	0.57	0.38	0.60	0.63
DD10	1.23	2.22	1.33	1.26	1.18	1.41	1.72	1.57
DD11	1.24	1.95	0.94	1.64	1.70	1.19	1.96	2.02
Geometric Mean	0.97	1.57	0.94	1.21	1.11	1.06	1.41	1.30

The evaluation results indicate a slight under-prediction by the model using default and low wind model options using all turbulence data. The model over-predicts for the modeling runs that omit all turbulence or only the horizontal turbulence. We also include modeling results with the AERMOD default options, but with turbulence omitted, to reflect the modeling performance with input data similar to typical airport data. That model run shows a substantial over-prediction tendency, indicating the benefits of the use of observed turbulence data, and the need without such data to employ the low wind options for improved AERMOD model performance.

We also computed and then ranked the 99th percentile peak daily 1-hour maximum concentration – the "design concentration" - (both predicted and observed) for each of the 9 monitors. We then plotted the ranked pairs as a Q-Q plot for each model tested. The highest ranked pair was examined closely because that pair of values represents the controlling design concentration for observations and model predictions. Due to the fact that SO_2 monitored concentrations can have a 10% uncertainty due to calibration tolerances permitted by EPA[18], it is possible that predicted/observed ratios within 10% of 1.0 are unbiased.

The results indicate that the modeling options for default AERMOD with turbulence included, both low wind options with only vertical turbulence included, or just the ADJ_U* option with all turbulence included are nearly unbiased for this test. The default model with no turbulence is approaching a factor-of-2 over-prediction and it is the worst-performing model (see Figure 4). The low wind option run (both ADJ_U* and LOWWIND3) with no turbulence (Figure 5) still shows an over-prediction, and with full turbulence shows a slight under-prediction (Figure 6), but with consideration of impacts from an unmodeled nearby background source (Bowline Point), it could be within the 10% uncertainty range for an unbiased model. The model with both low wind options and no turbulence shows a modest over-prediction. If only ADJ_U* is used, then the use of full turbulence input shows a modest over-prediction, and eliminating all turbulence leads to over-predictions. Therefore, it appears that the only case in which horizontal (but not vertical) turbulence should be removed (to prevent underpredictions) from input to AERMOD is in the case for which both ADJ_U* and LOWWIND3 are employed.

Figure 4 Q-Q Plot of the Ranked 4th Highest (99th Percentile) Daily 1-hour SO_2 Concentrations for Each Monitor Using AERMOD Default (No Turbulence)

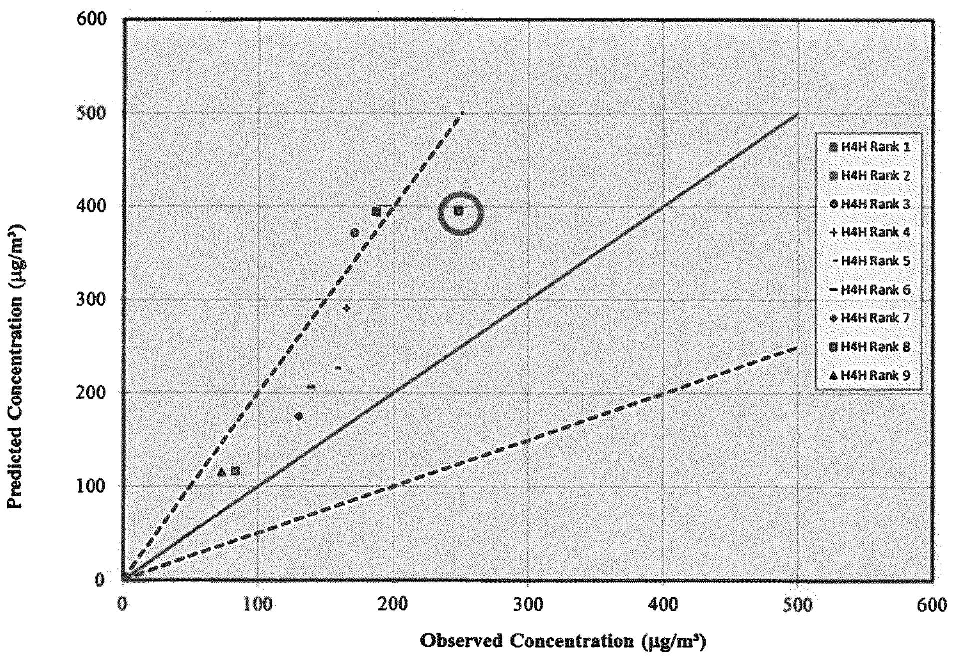


Figure 5 Q-Q Plot of the Ranked 4th Highest (99th Percentile) Daily 1-hour SO_2 Concentrations for Each Monitor Using AERMOD LOWWIND3 (No Turbulence)

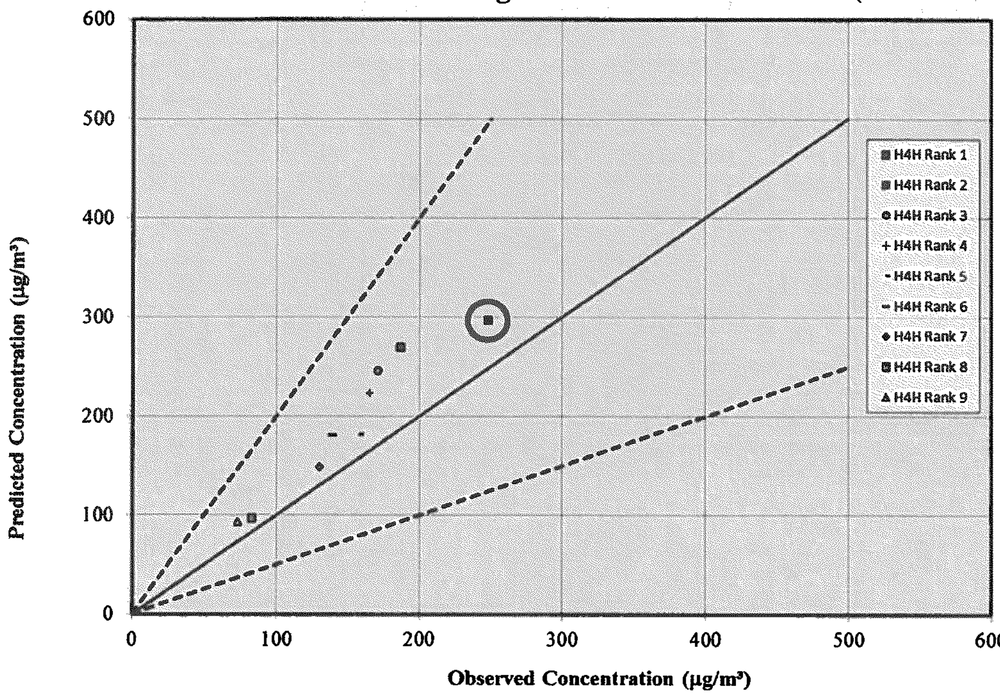
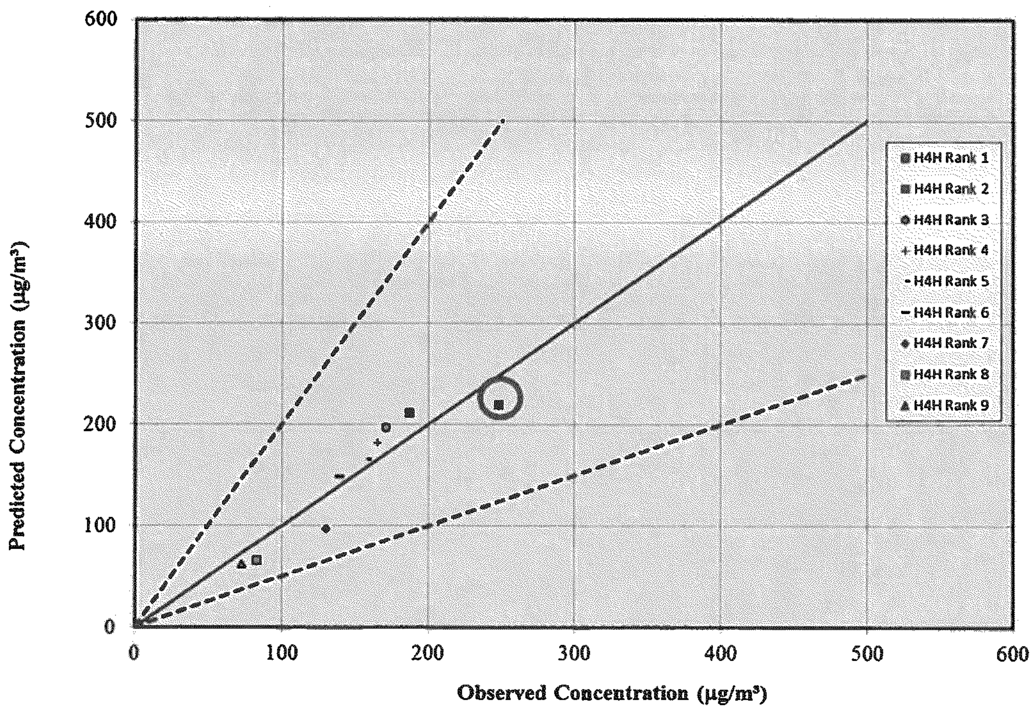


Figure 6 Q-Q Plot of the Ranked 4th Highest (99th Percentile) Daily 1-hour SO_2 Concentrations for Each Monitor Using ADJ_U* and LOWWIND3 (All Turbulence Used)



CLIFTY CREEK EVALUATION RESULTS

Description of Field Study Setting

The Clifty Creek Power Plant is located in rural southern Indiana along the Ohio River with emissions from three 208-m stacks during this study. The area immediately north of the facility is characterized by cliffs rising about 115 m above the river and intersected by creek valleys. Six nearby SO_2 monitors (out to 16 km from the stacks) provided hourly averaged concentration data. A map of the terrain overlaid with the monitoring sites is shown in Figure 7. Hourly-varying emissions (for this base-loaded with no SO_2 controls in 1975) were provided for the three stacks. Meteorological data from a nearby 60-m tower for 1975 were used in this evaluation study. The meteorological data included winds at 60 m and temperature at 10 m. The on-site meteorological tower did not include turbulence measurements. This database was also used in a major EPA-funded evaluation of rural air quality dispersion models in the 1980s[19].

AERMET/AERMOD version 15181 was run using the following two configuration options (fewer options than Lovett due to the lack of turbulence data):

- AERMET Default / AERMOD Default
- AERMET ADJ_U* / AERMOD LOWWIND3.

Results of the 99th Percentile Concentration Comparison

The 4th highest (99th percentile) daily peak 1-hour SO_2 concentrations observed at each monitor location were compared against the model-predicted concentrations. This comparison was performed for AERMOD version 15181 default and the low wind options. The 1-hour SO_2 design concentrations for the Clifty Creek evaluation database are plotted in Figure 8.

Figure 7 Map of Clifty Creek Power Plant and Monitor Locations

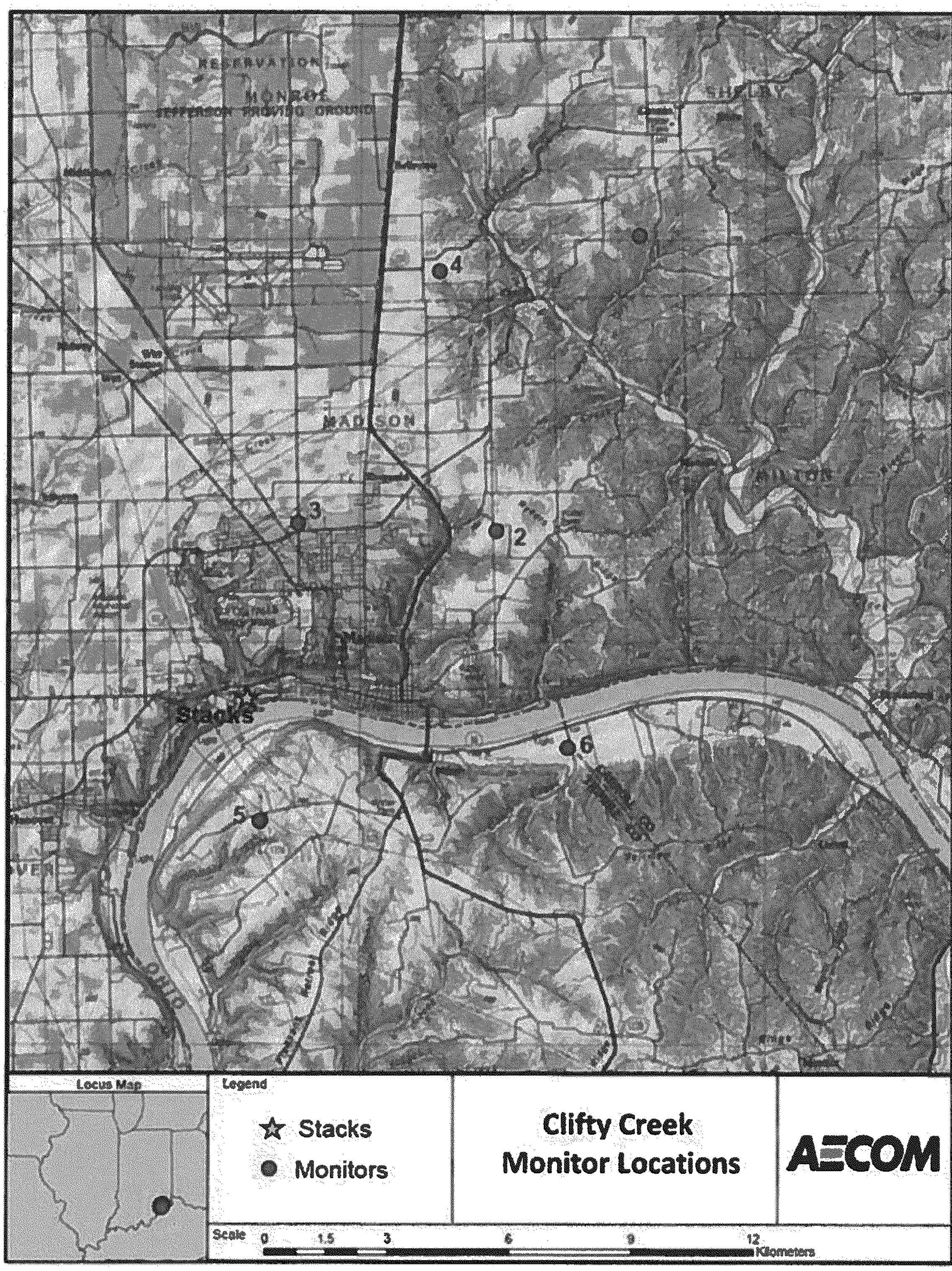


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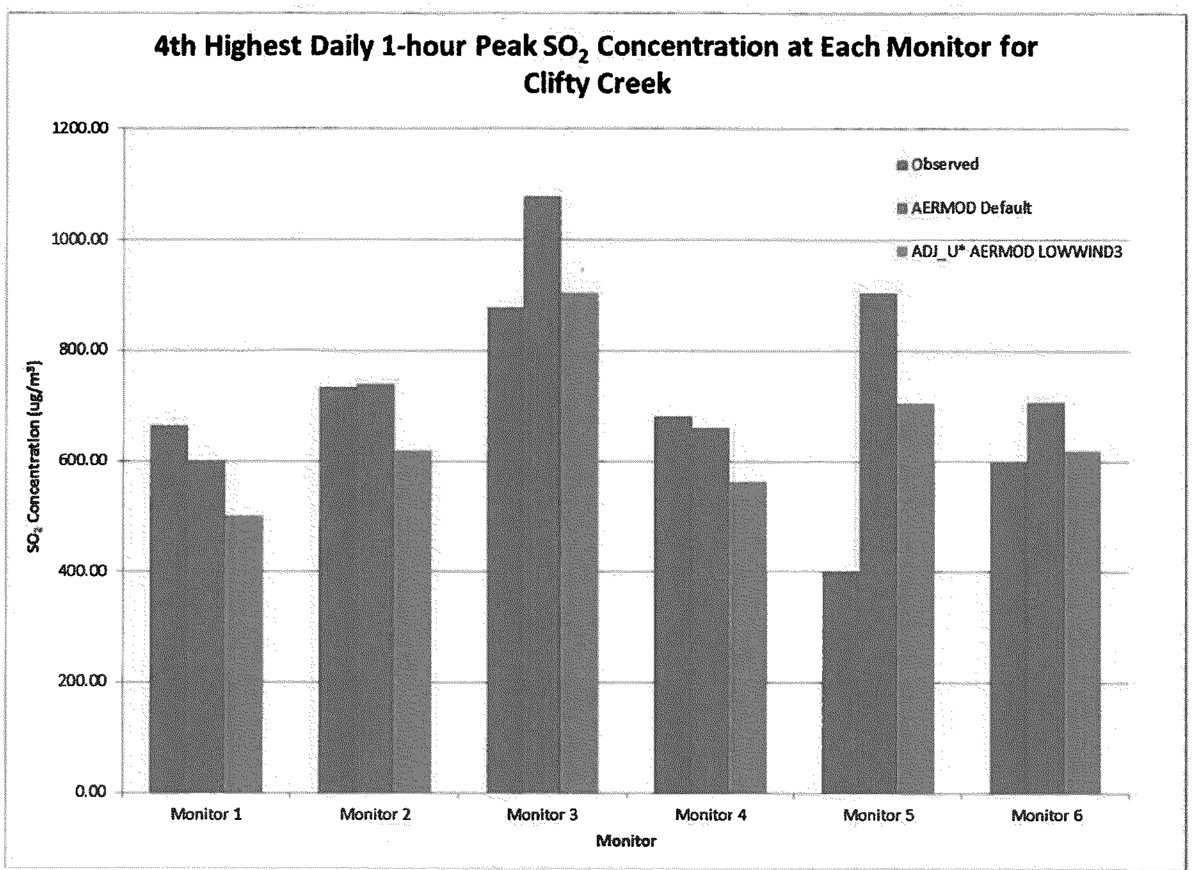
Figure 8 Histogram of the 4th Highest Daily Peak 1-hour SO_2 Concentrations



The overall results indicate the following:

- The highest design concentration over all monitor sites for <u>both</u> default and low wind options are higher than its observed counterpart. The over-prediction for the default option is larger.
- The AERMOD v15181 default highest design concentration from all monitor sites is greater than the low wind result.
- Model-predicted design concentrations being higher or lower than observed were relatively evenly split across the six monitors.

Discussion of Clifty Creek Evaluation Results

RHC statistics were calculated for 1) the top twenty-six 1-hour, 2) the 4th highest 1-hour (using all hours), and 3) the 4th highest daily 1-hour averaging periods of SO_2 concentrations for each monitor site. A geometric mean of these ratios were then calculated to gain a better understanding of the overall model performance. The results for the third set of statistics are summarized in Table 2. Overall, the results indicate the two modeling approaches are nearly unbiased, with the default run slightly over-predicting, while the low wind options run is slightly under-predicting. The overall result for the low wind options were within the 10% uncertainty for monitored SO_2 concentrations.

Table 2 Ratio of Predicted-to-Observed Robust 4th Highest Daily Peak Concentration (R4HC; 99th Percentile) for Each Monitor at Clifty Creek

Monitor	AERMOD 15181 Default	AERMOD 15181 LOWWIND3
1	0.81	0.79
2	0.86	0.75
3	1.30	1.06
4	0.75	0.65
5	2.47	1.62
6	1.35	1.08
Geometric Mean	1.14	0.94

To provide a graphical depiction of the performance of the model options for predicting the 1-hour SO_2 NAAQS, we computed and then ranked the 99th percentile peak daily 1-hour maximum concentration (both predicted and observed) for each of the 6 monitors. We then ranked the 6 observed and predicted values independently and plotted the ranked pairs as a Q-Q plot for each model tested:

- Figure 9 for AERMET Default / AERMOD Default, and
- Figure 10 for AERMET ADJ_U* / AERMOD LOWWIND3.

An examination of the circled point in each figure (paired predicted and observed design concentrations) indicates that both modeling approaches over-predict for the controlling design concentration, but the default model over-predicts more.

Figure 9 Q-Q Plot of the Ranked 4th Highest (99th Percentile) Daily 1-hour SO_2 Concentrations for Each Monitor Using AERMOD Default

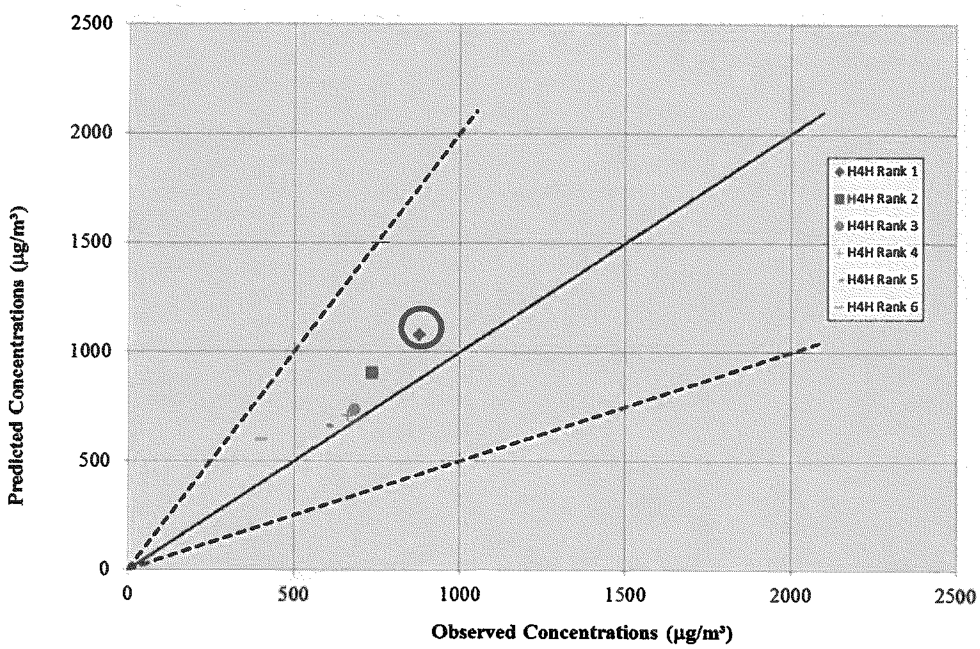
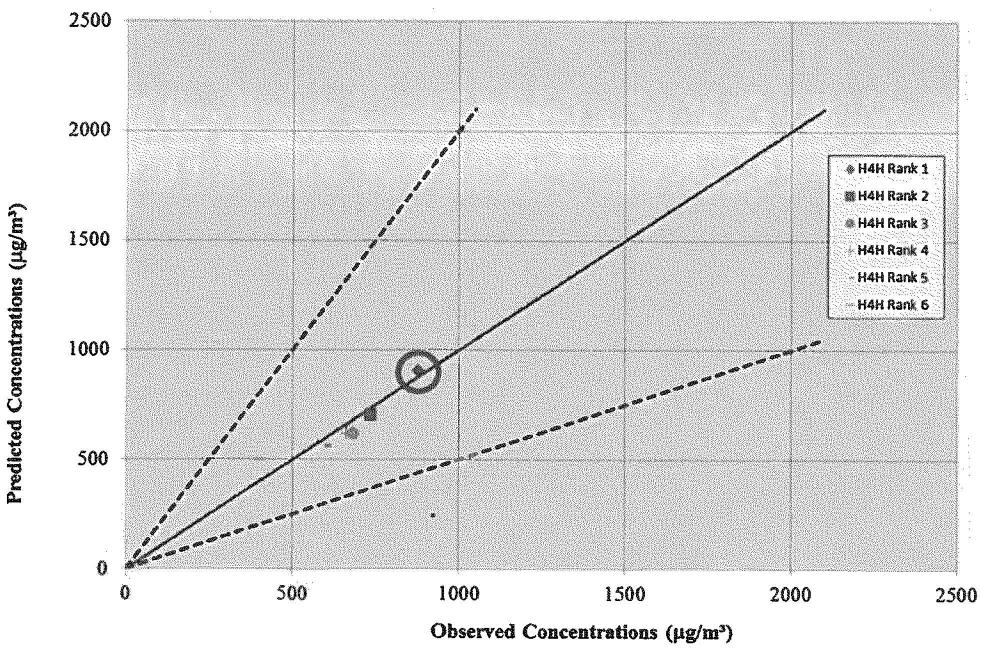


Figure 10 Q-Q Plot of the Ranked 4th Highest (99th Percentile) Daily 1-hour SO_2 Concentrations for Each Monitor Using ADJ_U* and LOWWIND3



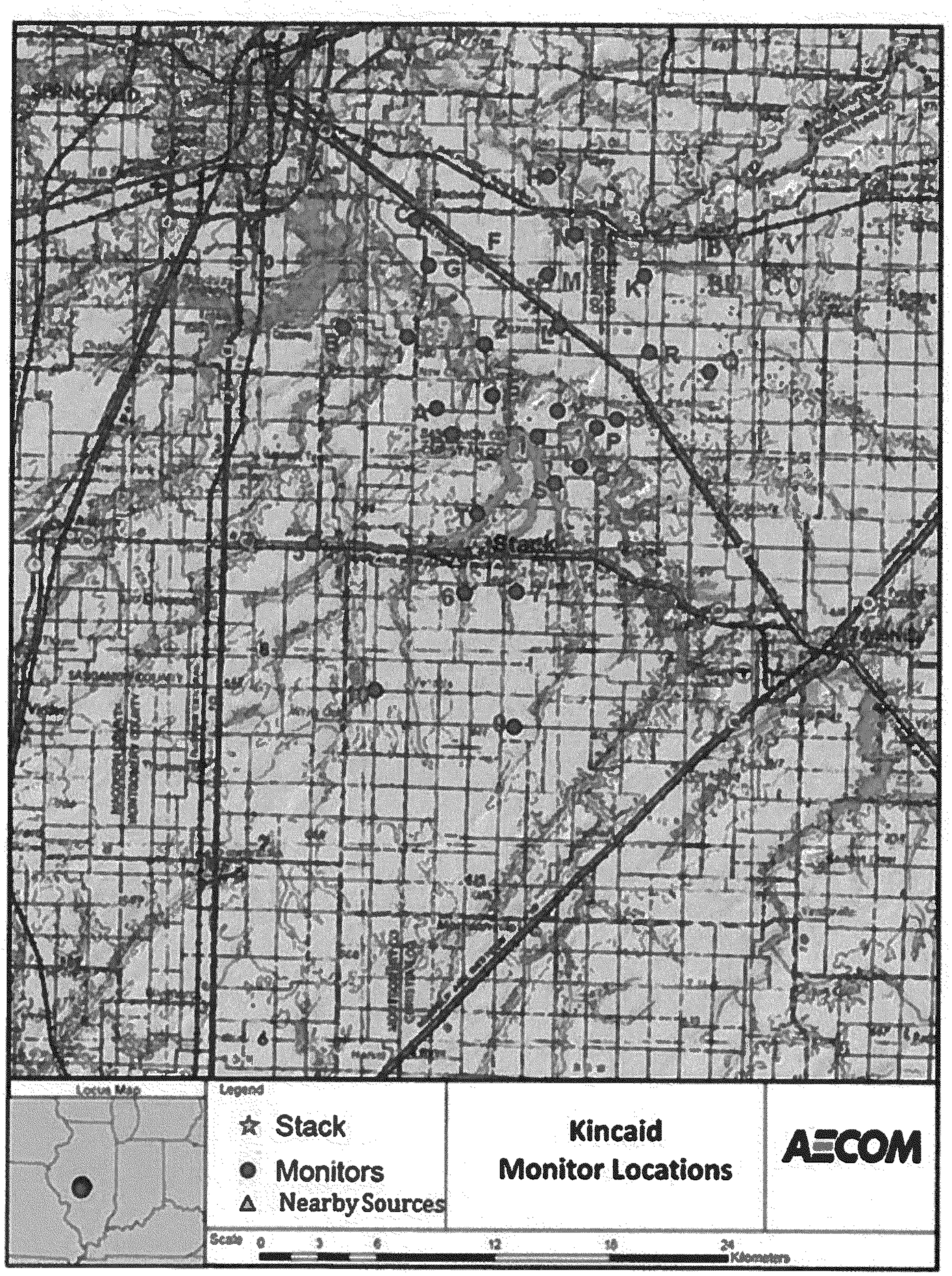
KINCAID FIELD STUDY

The Kincaid SO_2 study[20,21] was conducted at the Kincaid Generating Station in central Illinois, about 25 km southeast of Springfield, Illinois. It involved a buoyant, continuous release of SO_2 from a 187-m stack in rural flat terrain. The study included about seven months of data between April 1980 and June 1981 (a total of 4,614 hours of samples). There were 28 operational SO_2 monitoring stations providing 1-hour averaged samples from about 2 km to 20 km downwind of the stack. A map of the terrain overlaid with the monitoring sites is shown in Figure 11. Meteorological data included wind speed, direction, horizontal turbulence, and temperature from a tower instrumented at 2, 10, 50, and 100 m levels, and nearby National Weather Service (NWS) data. Vertical turbulence measurements were also included in the onsite tower data at 100-m level.

A review of the monitor-by-monitor differences between modeled and observed design concentrations indicates that monitors near unaccounted-for nearby sources of SO_2 are significantly affecting the modeling results. From Figure 11, it is clear that monitors C, G, F, 1, and B are relatively close to the Dallman plant in the northwestern part of the field study domain. It is also evident that monitors 6, 7, and 10 are relatively close to the local coal preparation plant.

Since there appear to be significant contributions from un-modeled SO_2 sources, this evaluation database, without a correction to add the unmodeled sources, is not appropriate for inclusion in this study. The analysis that is needed to determine the magnitude of the unmodeled emissions is beyond the scope of this study. Although the Kincaid SO_2 experiment may be seriously compromised without information on the unmodeled sources, it may be possible to reasonably estimate the approximate magnitude of the emission sources that were missed for future updates of this database. In contrast, the Kincaid SF_6 study is not similarly affected because of the single source of this tracer release. However, the extent of the time period covered by the intensive Kincaid tracer study is much less than that of the SO_2 study, which limits its applicability for a full-year SO_2 database evaluation.

Figure 11 Map of Kincaid and Monitor Locations, Along with Nearby Emission Sources Omitted from the Evaluation Database



OTHER TALL-STACK EVALUATION DATABASES

Evaluation of the low wind modeling approaches for North Dakota and Gibson Generating Station are described in details in a November 2015 Journal of the Air & Waste Management Association article[3]. This section presents a brief summary of the databases and the evaluation results.

An available 4-year period of 2007-2010 was used for the Mercer County, ND evaluation database with five SO_2 monitors within 10 km of two nearby emission facilities (Antelope Valley and Dakota Gasification Company), site-specific meteorological data at one of the sites (10-m level data in a low-cut grassy field), and hourly emissions data from 15 point sources (all tall stacks). The terrain in the area is rolling and features three of the monitors above or close to stack top for some of the nearby emission sources. Although this modeling application employed sources as far away as 50 km, the proximity of the monitors to the two nearby emission facilities meant that emissions from those facilities dominated the impacts.

The overall evaluation results for the North Dakota database indicated the following:

- The highest modeled design concentration at all monitor sites for both default and low wind options are higher than observed.
- The AERMOD v15181 default highest design concentration from all monitor sites is greater than the ones using the low wind options.
- For the monitors in simple terrain, the evaluation results were similar for both the default and the low wind options.
- The evaluation result for the monitor in the highest terrain shows that the ratio of modeled to monitored concentration is more than 2, but when this location is modeled with the low wind options, the ratio is significantly better, at less than 1.3.

An available 3-year period of 2008-2010 was used for the Gibson Generating Station evaluation database in southwest Indiana with four SO_2 monitors within 6 km of the plant, airport hourly meteorological data (from Evansville, Indiana 1-minute data, located about 40 km SSE of the plant), and hourly emissions data from one electrical generating station (Gibson). The terrain in the area is quite flat and the stacks are tall. Due to the fact that there are no major SO_2 sources within at least 30 km of Gibson, we modeled emissions from only that plant.

The overall evaluation results for Gibson indicated the following:

- The highest modeled design concentration from all monitor sites for both default and low wind options are higher than observed.
- The AERMOD v15181 default highest design concentration from all monitor sites is greater than that for the low wind options.

- The ratios of the modeled to monitored concentrations at each monitor are greater than 1.0. The default option over- predicts by about 41-52% at two of the monitors and by about 12-28% at the other two monitors. The low wind options reduce the over-predictions to 5-28% at the four monitors

BRIEF REVIEW OF TRACY EVALUATION

For the databases used for EPA's Complex Terrain Model Development project (documented in several "Milestone Reports"; the one for Tracy is the Fifth Milestone Report[16]), the turbulence data sigma-theta in the horizontal and sigma-w in the vertical) as archived for use in the CTDMPLUS model was processed using a full 60-minute average. Shortly after the databases were developed, EPA issued a year 1987 and later a year 2000 updated guidance document for site-specific meteorological measurements (Meteorological Monitoring Guidance for Regulatory Modeling Applications). The guidance for taking direct measurements of horizontal and vertical turbulence recommends using 15-minute averaging times and averaging the 4 values to obtain an hourly average. The reason for this is for computing stability class (for models in use before AERMOD), but this method also provides short-term turbulence data appropriate for plume dispersion in AERMOD.

The use of 15-minute averages for sigma-theta and sigma-w avoids overestimates of the plume dispersion in AERMOD with the following considerations:

- For the horizontal (crosswind, lateral) turbulence (sigma-theta), the use of 15-minute averages does not account for wind direction meandering during the course of an hour to the extent that the full 60-minute average does. It is important to include meander unless the model separately accounts for it (CTDMPLUS does not). However, since AERMOD (especially with the low wind options) accounts for plume meander separately, the use of 60-minute averages for sigma-theta would "double-count" the meander, and that would be expected to result in a model underprediction.

- For the vertical turbulence (sigma-w), the use of 15-minute averages helps to provide AERMOD with intra-hour averages that avoid the consideration of updrafts and downdrafts that do not disperse the plume, but which affect the longer-term (60-minute) average by increasing the value of sigma-w. The use of a 60-minute average leads to a modeled dilution of the plume for impacts in complex terrain.

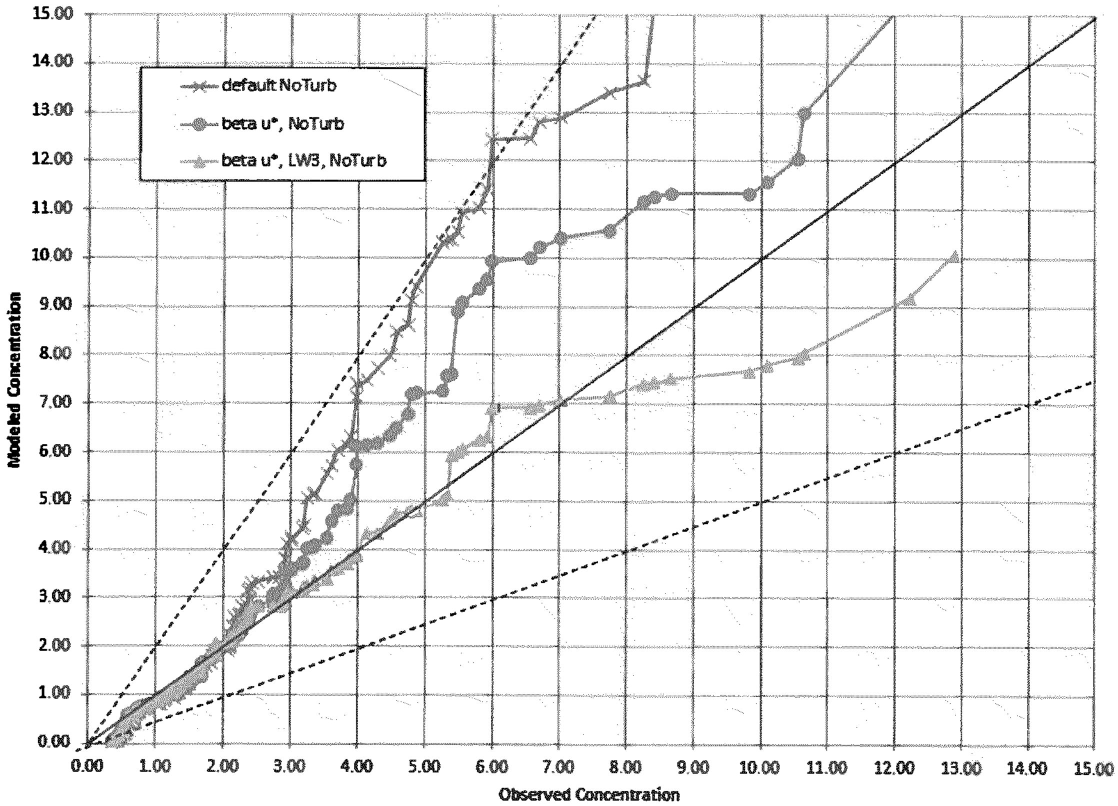
Due to the 60-minute averaging times for the Tracy turbulence data, we recommend for this database as used in AERMOD modeling that the turbulence data should not be used. We re-ran AERMOD with default and low wind options with the turbulence data removed from the model input; the results are shown in Figure 12.

The results without turbulence used show the following:

- The default AERMOD run shows an overprediction tendency of about a factor of 2.
- The use of the ADJ_U* option (but not LOWWIND3) shows an overprediction tendency of about 50%

• The use of the ADJ_U* plus the LOWWIND3 options shows a nearly unbiased prediction over the entire range of concentrations. There are modest underpredictions for the peak concentrations and modest overpredictions for the mid-range of concentrations.

Figure 12 Tracy Evaluation Results with Meteorological Data Omitting Turbulence Data



CONCLUSIONS

The model evaluation for AERMOD's low-wind options was conducted in this study to target the 1-hour SO_2 design concentration (99^{th} percentile daily maximum 1-hour concentration per year). This statistic is more pertinent for tall combustion sources than the RHC statistic established by EPA in the early 1990's due to the promulgation in 2010 of short-term probabilistic standards for SO_2 and NOx.

Model evaluation results are considered for the latest version of AERMOD (version 15181) on all of the tall-stack databases discussed in this report (except for Kincaid SO_2, which is set aside due to source inventory problems). The results for the four remaining databases show that the proposed low wind options (ADJ_U* and LOWWIND3) over-predict the 1-hour SO_2 design concentration, while the default model over-predicts to a greater degree. This is especially the case in complex terrain (Lovett) without site-specific turbulence data.

Of the four full-year databases considered, only one (Lovett) had turbulence data (15-minute averages), and AERMOD with only vertical turbulence data performed well (virtually unbiased) for the low wind options, while the use of both vertical and horizontal turbulence resulted in slight under-prediction if both the ADJ_U* and LOWWIND3 options were employed. If only the ADJ_U* option was employed, then the use of full turbulence data led to a slight over-prediction, and exclusion of turbulence led to higher over-predictions.

Based on these results, we conclude for the tall-stack databases reviewed in this study that the use of low wind options (ADJ_U* and LOWWIND3) will modestly predict the 1-hour SO_2 design concentration if observed horizontal turbulence data is not used. This finding indicates that the LOWWIND3 option plus inclusion of horizontal turbulence measurements may tend to over-correct for wind meander. Since the LOWWIND3 option does not affect the vertical plume spread, it is appropriate to use the observed vertical turbulence measurements in conjunction with the low wind options. Also, if only the ADJ_U* option is used, then the use of both horizontal and vertical turbulence (as shown in the case of Lovett) is acceptable.

This report augments information previously provided to EPA, which includes a peer-reviewed paper involving the North Dakota and Gibson evaluations using ADJ_U* and LOWWIND3 as well as a supplemental evaluation using LOWWIND3 after it became available.

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KEYWORDS

SO_2, AERMOD, modeling, low wind

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ATTACHMENT 2

Review of AERMOD Low Wind Option Evaluation for the Tracy Power Plant Tracer Experiment

Robert Paine and Jeff Connors, AECOM

April 18, 2016

Introduction

Some of the most restrictive dispersion conditions and the highest model predictions for AERMOD[1] (EPA's preferred dispersion model for short-range applications) occur under low wind speed conditions. Before 2010, there had been limited model evaluation for these conditions. After a 2010 API-sponsored study conducted by AECOM[2], the United States Environmental Protection Agency (EPA) proceeded to implement various improvements to the AERMET meteorological pre-processor (to address under-predictions of the friction velocity in low wind conditions) as well as the AERMOD dispersion model (to address under-predictions of the lateral wind meander). There have been several AERMOD releases with various options to address this issue, as well as additional model evaluations to further test the AERMOD implementation.

In July 2015, EPA proposed[3] an updated set of options for AERMET ("ADJ_U*") and AERMOD ("LOWWIND3") for implementation as default options in the model. As part of the public comments to EPA's proposal, the Sierra Club provided[4] new evaluations for 5 databases, for which three of these led to questions as to whether these low wind options are sufficiently protective of air quality standards, especially the short-term SO_2 and NO_2 National Ambient Air Quality Standards (NAAQS).

The specific evaluation databases selected by the Sierra Club included Baldwin, Kincaid, Lovett, Tracy, and Prairie Grass, with features noted below.

- Baldwin (1-hr SO_2): Rural, flat terrain, 3 stacks, stack height = 184.4 m, 1 full year
- Kincaid (1-hr SO_2): Rural, flat terrain, 1 stack, stack height = 187 m, about 7 months
- Lovett (1-hr SO_2): Rural, complex terrain, stack height = 145 m, 1 full year
- Tracy (1-hr SF_6): Rural, complex terrain, 1 stack, stack height = 90.95 m, 3 weeks (August 1984) with several tracer release hours
- Prairie Grass (1-hr SF_6): Rural, flat terrain, 1 stack, release height = 0.46 m (no plume rise), several tracer release hours.

The Sierra Club evaluations for the Baldwin and Prairie Grass field studies led to a conclusion that the AERMOD low wind options were either overpredicting or nearly unbiased, but results for Lovett, Kincaid, and Tracy showed underpredictions for the peak concentration at each monitor (the "Robust Highest Concentration").

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[1] Available at https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

[2] Paine, R.J., J.A. Connors, and C.D. Szembek, 2010. AERMOD Low Wind Speed Evaluation Study: Results and Implementation. Paper 2010-A-631-AWMA, presented at the 103rd Annual Conference, Air & Waste Management Association, Calgary, Alberta, Canada.

[3] 80 FR 45340, July 29, 2016.

[4] EPA Docket Item, 2015. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2015-0310-0114.

In follow-up work, AECOM reviewed the Sierra Club work and provided a rebuttal evaluation[5] for certain long-term (at least 1-year) databases: Lovett and Clifty Creek. The Kincaid SO_2 evaluation database was found in this study to be unusable due to local SO_2 sources that were not accounted for in the inventory. The basic conclusion from the AECOM rebuttal evaluation was that for the 99th percentile statistic associated with the SO_2 NAAQS, the use of the ADJ_U* LOWWIND3 options were sufficiently protective of the NAAQS.

Recent Sierra Club Comments on the Tracy Evaluation

The AECOM rebuttal evaluation did not address Tracy because of its short duration. However, the Sierra Club mentioned this database again in additional comments[6] made to the EPA Consent Decree docket on March 31, 2016. The Sierra Club comments can be summarized as follows.

- The proposed low wind options "undermine the reliability and credibility of the modeling".
- Applying these options to the original validation studies performed for AERMOD in some cases "quite significantly reduces modeled impacts as compared to real-world data, particularly so in the case of the Tracy validation study data."
- The Sierra Club provides quantile-quantile plots showing their model evaluation results, which are reproduced here in Figures 1 and 2. Figure 2 shows an underprediction tendency with the use of the low-wind options.
- The Sierra Club also criticizes the use of 1974 National Oceanic and Atmospheric Administration (NOAA) tracer databases (as being "severely flawed and outdated") and with a limited sample size.

Response to the Sierra Club Comments

It is important to realize that the AERMOD evaluations[7] referenced by the Sierra Club were conducted about 13 years ago. It must be understood that after these evaluations were conducted, there were several developments that increased the frequency of low wind input data used in AERMOD, and which "exposed" possible shortcomings in the model for these conditions:

- Observing stations at airports were converted in many cases to sonic anemometers ("ice free"), lowering the starting wind speed from 3 knots to virtually zero.
- The archival of 1-minute wind data made it possible for EPA to write a new pre-processor program to AERMET (AERMINUTE)that significantly increased the number of hours with wind speeds under 1 m/s, thus further testing the model in these conditions.
- The very nature of a steady-state model that assumes a 50-km distance coverage within 1 hour is invalidated for very low wind speeds.

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[5] Available at https://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2014-0464-0326, Exhibit 7.

[6] Submittal to docket EPA-HQ-OAR-2014-0464 by Zachary Fabish, Sierra Club, on March 31, 2016.

[7] Available at https://www3.epa.gov/ttn/scram/7thconf/aermod/aermod_mep.pdf.

Figure 1: Tracy Evaluation Results with Default Options

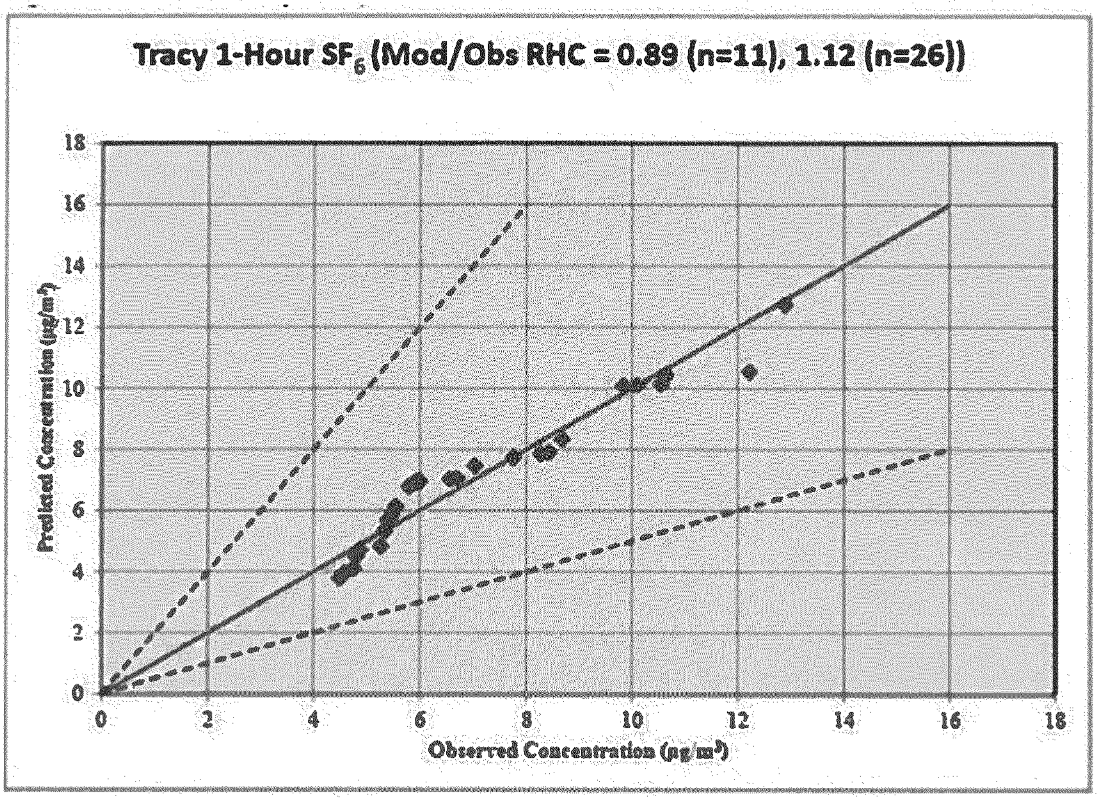
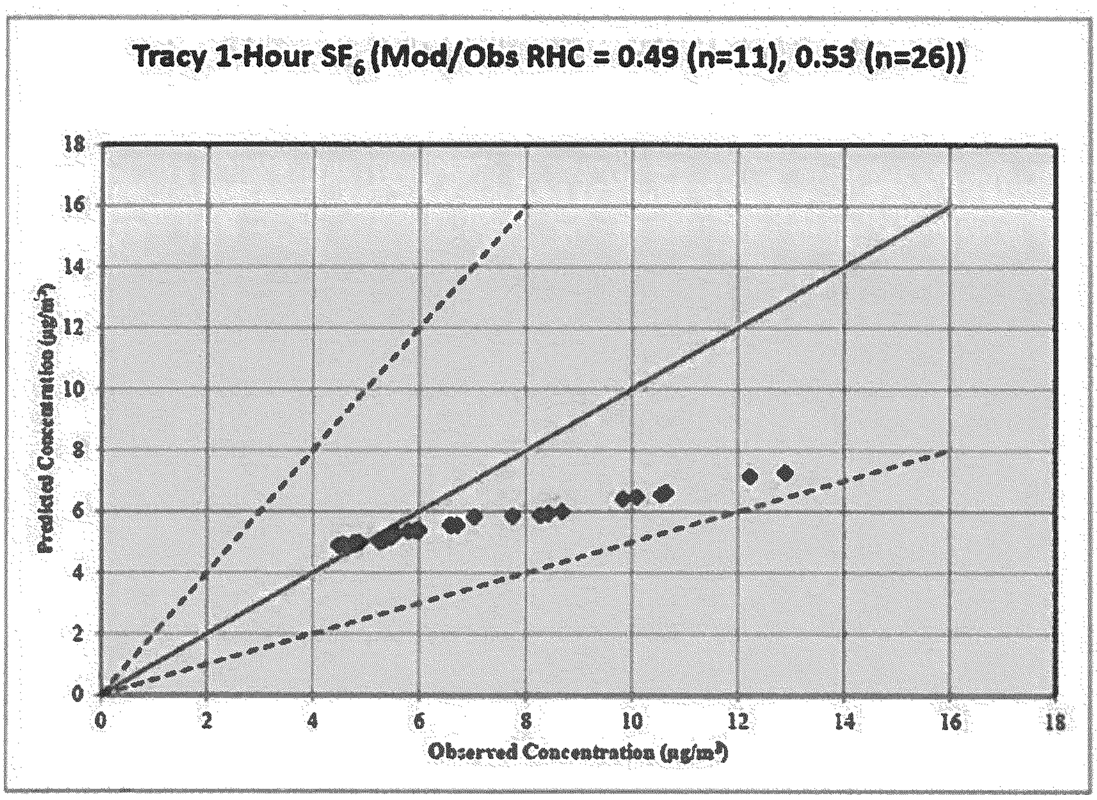


Figure 2: Tracy Evaluation Results with ADJ_U* and LOWWIND3 Used



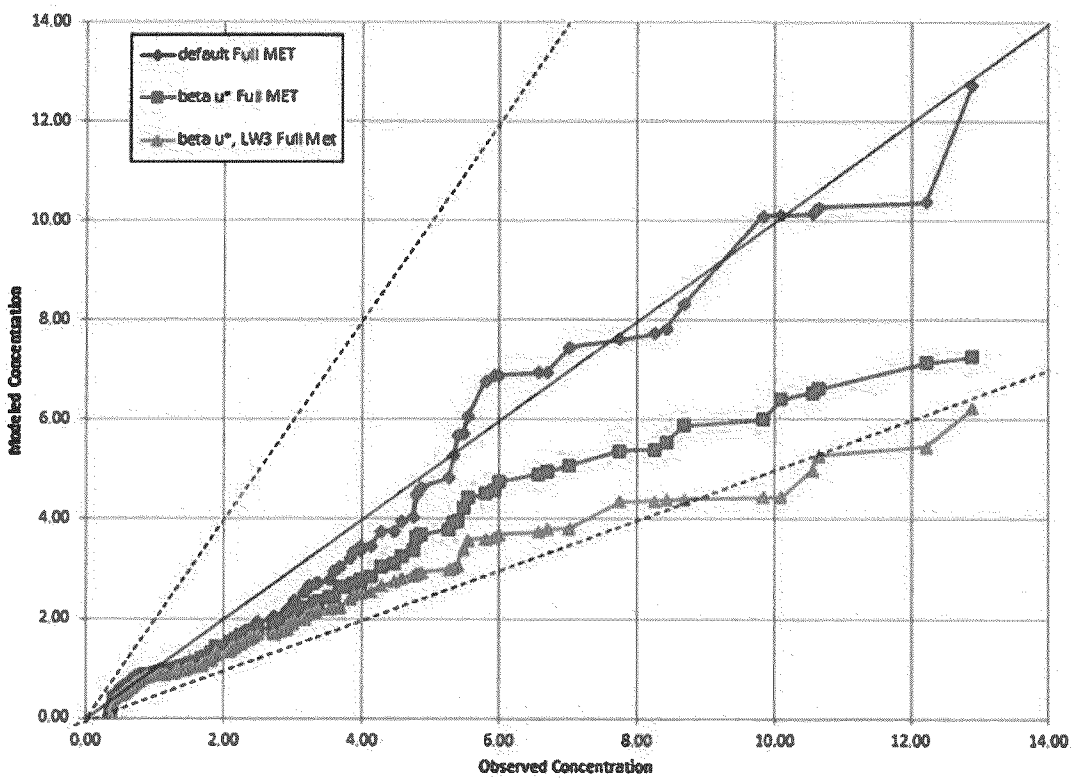
These issues led to the scientific investigations noted above that have resulted in the EPA proposals for these beta low wind options as part of the revisions to Appendix W.

In terms of the 1984 Tracy database, its age is not that much less than the 1974 NOAA databases. It also only spanned a 3-week duration which included only partial-day coverage (up to 11 hours at most on any given day). These aspects limit the Tracy database's usefulness for the SO_2 NAAQS, which is based upon a full year and full daily review of hourly monitor observations.

It is also important to note that the Tracy database was specifically designed for a model, CTDMPLUS[8], which was developed from the Tracy and other research-grade databases. This database and others involved in EPA's Complex Terrain Model Development project in the 1980s had unique aspects that require additional caution when they are used for AERMOD evaluations, as is noted below.

Our attempts to replicate the Tracy evaluation results noted by the Sierra Club provided the results for the quantile-quantile plots of the Robust Highest Concentrations shown in Figure 3. The results presented in Figure 3 use the full meteorological database and receptors in the EPA archives (available at https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm). These results do indicate an under-prediction for the low wind options.

Figure 3: Tracy Evaluation Results with Full Meteorological Data



[8] Available at https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#ctdmplus.

For the databases used for EPA's Complex Terrain Model Development project (documented in several "Milestone Reports"; the one for Tracy is the Fifth Milestone Report[9]), the turbulence data (sigma-theta in the horizontal and sigma-w in the vertical) as archived for use in the CTDMPLUS model was processed using a full 60-minute average. Shortly after the databases were developed, EPA issued a guidance document initially in 1987 and then updated in 2000[10] for site-specific meteorological measurements (Meteorological Monitoring Guidance for Regulatory Modeling Applications). The guidance for taking direct measurements of horizontal and vertical turbulence recommends using 15-minute averaging times and averaging the 4 values to obtain an hourly average. The rationale for this is based on the stability class calculations (for models in use before AERMOD), but this method also provides short-term turbulence data appropriate for plume dispersion in AERMOD.

The use of 15-minute averages for sigma-theta and sigma-w avoids overestimates of the plume dispersion in AERMOD with the following considerations:

- For the horizontal (crosswind, lateral) turbulence (sigma-theta), the use of 15-minute averages does not account for wind direction meandering during the course of an hour to the extent that the full 60-minute average does. It is important to include meander unless the model separately accounts for it (CTDMPLUS does not). However, since AERMOD (especially with the low wind options) accounts for plume meander separately, the use of 60-minute averages for sigma-theta would "double-count" the meander, and that would be expected to result in a model under-prediction.
- For the vertical turbulence (sigma-w), the use of 15-minute averages helps to provide AERMOD with intra-hour averages that avoid the consideration of updrafts and downdrafts that do not disperse the plume, but which affect the longer-term (60-minute) average by increasing the value of sigma-w. The use of a 60-minute average leads to a modeled dilution of the plume for impacts in complex terrain.

Due to the 60-minute averaging times for the Tracy turbulence data, we recommend for this database that the turbulence data not be used when evaluating AERMOD as it already accounts for plume meander. We re-ran AERMOD with default and low wind options with the turbulence data removed from the model input; the results are shown in Figure 4.

The results without turbulence used show the following:

- The default AERMOD run shows an overprediction tendency of about a factor of 2.
- The use of the ADJ_U* option (but not LOWWIND3) shows an overprediction tendency of about 50%.
- The use of the ADJ_U* plus the LOWWIND3 options shows a nearly unbiased prediction over the entire range of concentrations. There are modest under-predictions for the peak concentrations and modest over-predictions for the mid-range of concentrations.

Conclusions

The Tracy AERMOD evaluations using the proposed low wind options need to be reviewed without the use of the full hourly-averaged turbulence data to avoid overestimating the turbulence input to AERMOD which occurs, in part, by double-counting the meander effect. Once this is done, it is evident that the default AERMOD options over-predict, and the low wind options show an improved and acceptable evaluation result.

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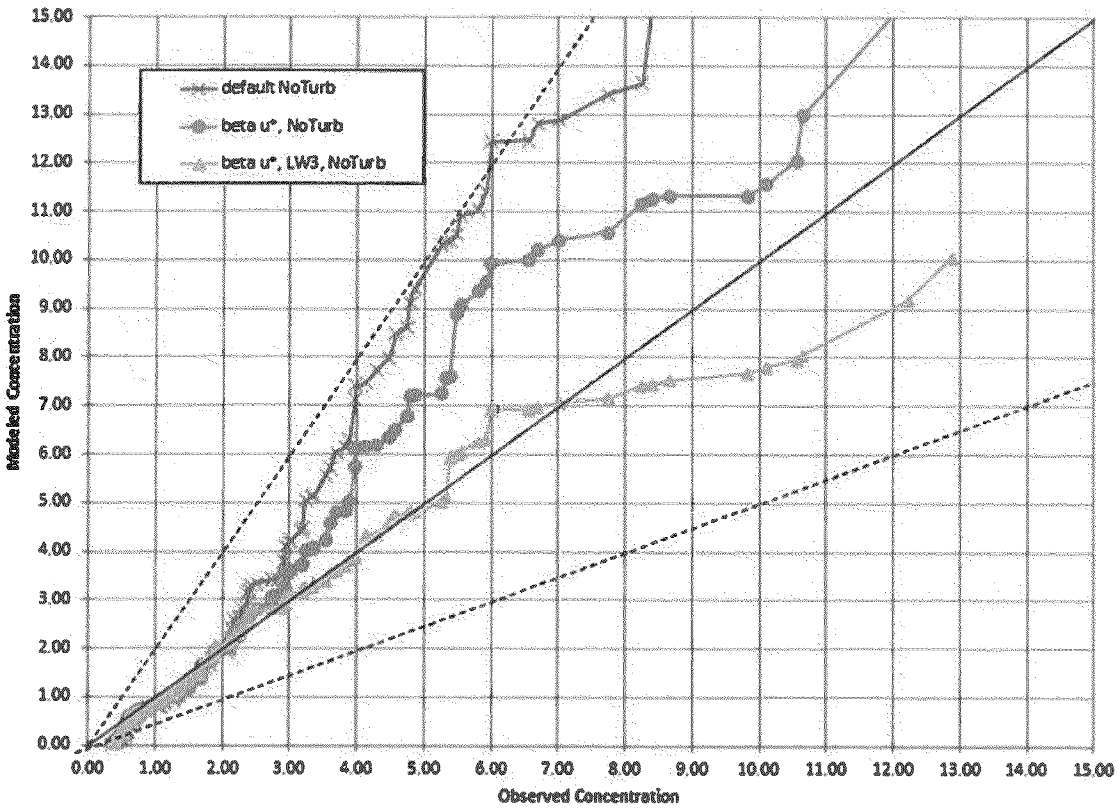
[9] DiCristofaro, D., Strimatis, D., Greene, B., Yamartino, R., Venkatram, A., Godden, D., Lavery, T., and Egan, B., 1986. EPA complex terrain model development : fifth milestone report - 1985. U.S. Environmental Protection Agency, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC. EPA/600/3-85/069.

[10] 2000 version is available at https://www3.epa.gov/scram001/guidance/met/mmgrma.pdf.

Figure 4: Tracy Evaluation Results with Meteorological Data Omitting Turbulence Data



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